NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

Technical Report
TR-2092-ENV

BIOCELL APPLICATION GUIDANCE

by

J. Trotsky
D. Pal

July 1998

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-018

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1998

3. REPORT TYPE AND DATES COVERED
Final: December 1997 - July 1998

4. TITLE AND SUBTITLE
BIOCELL APPLICATION GUIDANCE

5. FUNDING NUMBERS

6. AUTHOR(S)
J. Trotsky and D. Pal

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(S)
Naval Facilities Engineering Service Center
1100 23rd Ave.
Port Hueneme, CA 93043-4370

8. PERFORMING ORGANIZATION REPORT NUMBER
TR-2092-ENV

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Biocell technology is an innovative method for treating small quantities of soils contaminated with low to intermediate concentrations of petroleum hydrocarbons, which are usually found on Navy installations. The technology involves loading petroleum-contaminated soils into a dumpster or container, and stimulating aerobic microbial activity through aeration. Adding moisture and nutrients, such as nitorgen and phosphorus, enhances microbial activity. The microbial acitivity degrades the petroleum-based constituents adsorbed to soil particles, thus reducing the concentrations of these contaminants. The use of biocells to reduce the concentration of petroleum constituents in excavated soils through the use of aerobic biodegradation has been successfully demonstrated. The Army's Waterways Experiment Station (WES) developed a 10-yd^3 biocell that was tested at the Naval Construction Battalion Center, Port Hueneme, California in October 1996. A significant part of the WES research was aimed at simplifying the technology for an activity to build a 40-yd^3 system using readily available commercial materials. Based on WES's design and the successful demonstration of a 10-yd^3 biocell, NFESC has developed this document to provide Navy installations a general overview of the biocell technology, design, operation and maintenance procedures, and economics.

14. SUBJECT TERMS
Biocell technology, contaminated soils, petroleum hydrocarbons, aeration

15. NUMBER OF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	
Unclassified	Unclassified	Unclassified	UL

EXECUTIVE SUMMARY

Biocell technology is an innovative method for treating small quantities of soils contaminated with low to intermediate concentrations of petroleum hydrocarbons, which are commonly encountered at Navy installations. The technology involves loading petroleum-contaminated soils into a dumpster or container, and stimulating aerobic microbial activity within the soils through aeration. Adding moisture and nutrients such as nitrogen and phosphorus can enhance microbial activity. The microbial activity degrades the petroleum-based constituents adsorbed to soil particles, thus reducing the concentrations of these contaminants. Clean soil can then be returned to the original excavation site or used as fill where needed.

The applicability of biocells to reduce the concentration of petroleum constituents in excavated soils through the use of aerobic biodegradation has been demonstrated successfully. The Army's Waterways Experiment Station (WES) has developed the 10 yd^3 biocell, which was tested at the Construction Battalion Center, Port Hueneme, California in October 1996. A significant portion of the WES research was aimed at simplifying the technology for an activity to build a 40-yd^3 system using readily available commercial materials.

Based on WES's design and the successful demonstration of a 10-yd^3 biocell, the Naval Facilities Engineering Service Center (NFESC) has developed this document to provide Navy installations a general overview of the biocell technology, design, operation and maintenance procedures, and economics. Depending on factors such as, volume and type of contaminated soil to be treated, material handling, and the available area to construct the biocell, one may construct a single cell or a number of similar cells (modular approach). For consistency in calculations and comparisons, a baseline 40 yd^3 (8 ft wide by 22 ft long by 7 ft high) biocell is considered.

The economics section of this document details the cost effectiveness of operating a biocell. Soil can be treated in a 40 yd^3 container in amounts ranging from a small quantity, by simply filling a portion of the container, to a large quantity, by using multiple containers (modular approach). The unit costs per yd^3, amortized over 5 years with three operations per year, are \$40.83/yd^3 for one biocell, \$36.75/yd^3 for two biocells, and \$34.56/yd^3 for three biocells, respectively. When compared to off-site disposal costs, which range from \$40.00/yd^3 to \$480.00/yd^3, biocell technology could be a very cost effective option.

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INTRODUCTION

1.1 BACKGROUND

Many Navy installations face the problem of disposing of small quantities of petroleum hydrocarbon contaminated soils. These soils are generated at facilities that have, fuel stored in underground storage tanks (UST) and aboveground storage tanks (AST), maintenance and vehicle wash areas, and training areas where fuel has been spilled on the ground. Private industry also faces similar problems at service stations, maintenance garages, and other facilities where fuels are used.

Biocells use naturally occurring microbes to degrade fuels and oils into carbon dioxide and water. Under optimum nutrient, moisture, oxygen, and temperature conditions, native bacteria in the contaminated soil use the total petroleum hydrocarbons (TPH) as a food source. Clean soil can then be returned to the original excavation site or used as fill where needed. Volatile organic compounds (VOC) produced during the operation of the biocell are treated by using a granulated activated carbon (GAC) adsorption system. Biocells are capable of treating soils contaminated with petroleum-based fuels and lubricants, including diesel, jet fuel, and lubricating and hydraulic oils. The microbes use the contaminants as a food source and thus destroy them. By carefully controlling air flow and moisture levels, degradation rates can reduce the treatment time (Ref. 1).

The performance of biocell technology to reduce the concentration of petroleum constituents in excavated soils through the use of aerobic biodegradation has been demonstrated successfully. The Army's Waterways Experiment Station (WES) has developed a 10 yd^3 biocell, which was tested at the Naval Construction Battalion Center's National Test Site in Port Hueneme California in October 1996. A significant portion of the WES research was aimed at simplifying the technology to enable an activity to build a system using readily available commercial materials (Ref. 2). Figure 1-1 shows a picture of the 10 yd^3 biocell at the National Test Site, Port Hueneme, California.

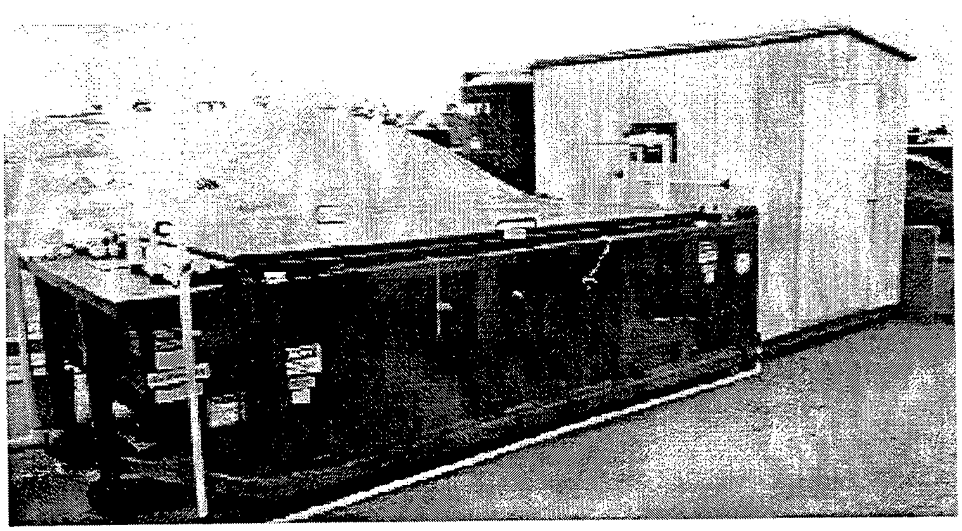

Figure 1-1 Picture of the 10 yd^3 biocell at the National Test Site, Port Hueneme, California.

Biocell treatment technology combines the best aspects of biopile, landfarming, and bioventing technologies. Although these technologies have been widely used in remediation, they have certain disadvantages. Biopiles, a cost-effective ex-situ technology, are cost effective in treating soil quantities of 200 yd^3 or greater. Bioventing, an in-situ technology, does not require excavation, but it does not protect groundwater from further contamination during the remediation process. The major disadvantage of landfarming is fugitive air emissions, which requires additional controls to meet regulatory compliance standards for treating small quantities of soil.

The biocell technology offers the following advantages:

- Biocell systems are relatively easy to design and construct.
- At most Navy sites, treatment can be completed in a relatively short period of 3 to 6 months.
- Biocells may be cost-competitive with off-site disposal.
- Biocells are applicable to a wide range of site conditions and petroleum-based contamination.

Biocells may not be effective for high contaminant concentrations (>50,000 ppm TPH). However, such levels are not common at UST and AST sites. During excavation, the peak contaminant levels are reduced because highly contaminated soil becomes mixed with surrounding clean soil. Biocells may not be effective in treating high molecular weight polycyclic aromatic hydrocarbons (PAH), pesticides, and chlorinated hydrocarbons. As mentioned earlier, biocells may not be cost effective for treating large quantities of soil greater than 200 yd^3 during one treatment duration. However, biocells may be cost effective at treating large quantities of contaminated soil when the soil is stockpiled and consecutive treatments are performed.

1.2 SCOPE OF THE DOCUMENT

The scope of this application guidance is limited to the aerobic treatment of soils contaminated with nonchlorinated petroleum hydrocarbons. Other contaminants including pesticides, PAH, and chlorinated hydrocarbons are beyond the scope of this document and would require more extensive studies.

This document provides technical guidance on the design, construction, operation, and maintenance of biocells to remediate soils contaminated with petroleum-based organic contaminants. Some examples are included to clarify principles and practices of biocell design, operation and maintenance by indicating some specific implementations, but many approaches are possible. The equipment vendors are listed in Section 3.1 for easy reference; however, the user is urged to develop their own list of vendors in their geographical locations.

1.3 TECHNOLOGY OVERVIEW

The biocell system consists of commercial roll-off dumpsters or containers converted into fully contained bioremediation units. Individual units can treat contaminated soil ranging in quantities from 20 to 40 yd^3 at a time, and several units may be combined at one site for larger soil volumes. Biocell containers have an impermeable liner to reduce the potential migration of leachate to the subsurface environment. A leachate collection system is installed at the bottom of the container to capture excessive moisture in the system. Perforated pipes, installed under the contaminated soil, are connected to a blower that facilitates the aeration of the soil. The blower pulls the air through GAC canisters. The container is covered with an impermeable liner to prevent the release of contaminants and/or contaminated soil to the environment, and to protect the soil from wind and precipitation. Biocells operate very effectively in temperate climates such as California and Hawaii, but can be operated effectively in Alaska and Iceland which have colder climatic conditions, by redesigning the biocell to introduce heated air through the aeration process. Figure 1-2 shows a simplified diagram of a biocell.

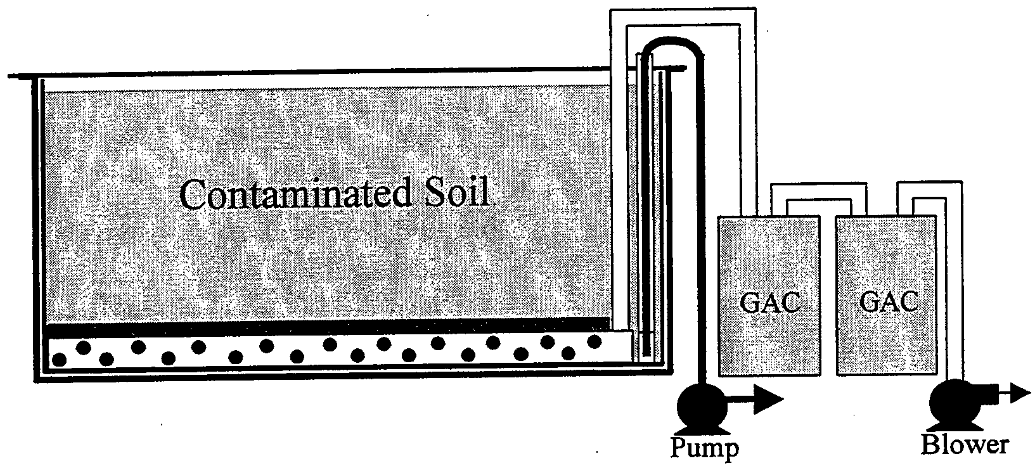

Figure 1-2 Simplified schematic of a biocell.

1.4 TECHNOLOGY APPLICABILITY

The use of a biocell to remediate petroleum hydrocarbon contamination from soils is generally applicable under the following conditions:

- Soil is contaminated primarily with petroleum hydrocarbons.
- Soil volumes to be treated range between 20 to 200 yd^3 per year.
- The TPH treatment target levels usually range from 500 to 1,000 mg/kg of soil. Actual target levels should be negotiated with the appropriate regulatory agency on a site-by-site basis.

In addition to the conditions listed above, certain site-specific conditions may dictate when biocell treatment may be a viable alternative. The project manager/engineer must perform an economic tradeoff study when considering this technology. This document has been designed to give the project manager the required guidance to make a sound technological evaluation on the applicability of a biocell technology for a specific soil remediation.

SECTION 2
PREDESIGN ACTIVITIES

This section describes some of the various activities required before designing a biocell. The activities include:

- Fully characterize soil to be treated.
- Estimate the amount of contaminated soil generated annually.
- Select a location for operating a biocell.
- Determine the number of biocells that will be needed.
- Consult with regulators and obtain the necessary permits.
- Identify the actions and equipment required by the permit, such as exhaust gas monitoring, soil sampling, and soil treatment levels.
- Identify labor requirements and coordinate with base facilities and applicable contractors.
- Prepare Health and Safety Plan and obtain required approvals.

2.1 SOIL CHARACTERIZATION

Before the biocell is constructed, the following initial data must be developed through laboratory analysis: hydrocarbon type and concentration, pH, moisture content, and particle-size distribution of the soil. After analyses of the various parameters, adjustments should be made to bring each design variable within the selection criteria. A methodology for parameter adjustment is outlined in Table 2-1.

Table 2-1 Soil Parameter Adjustment Methodology

Parameter Measured	Purpose and Comments	Selection Criteria	If Above Criterion Limits	If Below Criterion Limits
TPH	Determines the concentration of contaminants to be treated	TPH ≤ 50,000 mg/kg	Dilute with uncontaminated soil	Do not adjust soil
pH	Determines the need for amendments to adjust soil pH	pH @ 6 to 9	Adjust with acidic compound (sulfur)	Adjust with basic compound (lime)
Moisture Content	Determines the need to adjust moisture content	10 to 20% by weight	Allow soil to dry, use aeration system	Add water to achieve ~15%
Particle-Size Distribution & Analysis	Indicates the clay content which indicates if soil shredding is appropriate	Low clay or silt content Soil void volume ≥ 25%	Do not adjust soil	Shred soil

2.2 NUMBER OF BIOCELLS

The number of biocells required is determined by knowing the amount of contaminated soil generated annually. Based on a 40 yd^3 biocell operating three times per year, the number of biocells needed for certain quantities of soil generated per year is given below:

- For treating soil quantities less than 120 yd^3, one biocell will be adequate.
- For treating soil quantities between 120 and 240 yd^3, two biocells will be adequate.
- For treating soil quantities between 240 and 360 yd^3, three biocells will be adequate.

- For treating soil quantities between 360 and 480 yd^3, four biocells will be adequate.
- For treating soil quantities greater than 480 yd^3, the use of a biocell becomes uneconomical and a biopile is recommended.

Since the actual amount of soil generated and treatment times will vary, extra untreated soil may be stockpiled in the staging area until the biocell is ready for the next operation or another biocell may be used to treat this soil. The minimum amount of soil a 40 yd^3 container can treat is approximately 20 yd^3, unless modifications to the aeration system are made.

2.3 BIOCELL SITE SELECTION

Prior to the site selection process, it is recommended the project manager solicit suggestions from base authorities for potential biocell locations. The biocell can be located anywhere there is a relatively flat space available for stockpiling, mixing, and preparing soil, as well as electrical service required to operate equipment such as blowers and pumps. Stockpiling, mixing, and preparing soil must be performed on impermeable ground to reduce the potential for contaminant migration. The biocell may be located adjacent to a contaminated site, where the soil can be put directly into the biocell upon excavation, or in a centralized location where contaminated soil can be brought from various sites around the base. Useful amenities could include a covered concrete or asphalt area for soil storage. The size of this area will depend upon the quantity of contaminated soil to be received, the number of biocells, frequency of reception, expected retention time in the biocell, and any soil preparation requirements. For a 40 yd^3 biocell system, the minimum treatment area is approximately 300 ft^2, and will consist of the container, the pump shed, the leachate collection tank (typically a 55-gallon drum), and the off-gas treatment units (typically two GAC drums). Additional space will be needed for maneuvering soil-handling equipment, preparing the soil, and soil storage. Table 2-2 lists guidelines for selecting a biocell site.

Table 2-2 Biocell Site Selection Guidelines

Selection Parameter	Definition	Recommendation
Geography	Location and Natural and Improved Site Conditions	Select a relatively flat area with good drainage. The site should be located a minimum of 1,500 ft away from residential areas. An improved site, such as a parking lot or vacant storage yard, would be ideal.
Space Requirements	Area Required To Operate Biocell Facility	Provide clearance for equipment to maneuver and access the, soil storage area, processing area, biocell, pump shed, storage tank, and buffer zone.
Utilities	Electricity and Water Sources	110-volt lines should be sufficient. Check with electrical shop for actual requirements. A water truck may be used if a water tap is unavailable.
Soil Logistics	Transport, Handling, Storage of Soil	Soil handling equipment should be available for any required moving, mixing, and shredding of soil. Stored soil should be protected from the weather using a waterproof cover or coating.

2.4 REGULATORY COMPLIANCE

Regulatory compliance is a very critical step in the biocell deployment process. It may take several weeks after identifying the regulatory agencies to obtain the necessary permits required to operate a biocell. Every stage of the cleanup effort from planning to shutdown must be coordinated with the appropriate regulators.

Part of the regulatory process involves negotiating with the lead agency to set the target cleanup levels to be achieved through the proposed remediation. Prior to biocell construction, target cleanup levels should be negotiated with the lead agency based on the type of contaminant, extent of contamination, and limits of the technology.

Soil cleanup must meet the standards set by the regulating agencies. For a biocell, the target cleanup level for TPH contamination generally is in the range of 500 to 1,000 ppm for a 3-month treatment cycle. Levels of 100 to 500 ppm may be achievable for longer treatment periods (4 to 6 months). The actual target cleanup levels are dependent on the initial TPH level, soil type, desired final soil disposition, and the applicable regulatory agency's requirements. When the target cleanup levels are established, the project officer should request a written letter from the agency point of contact specifying the agreed-upon target cleanup levels and the corresponding method of final soil disposition.

It is recommended that the regulators be involved in the project from the very beginning. The project officer can use the following steps as a guideline to execute the permitting process:

Step 1. Establish the contamination type, contamination level, and amount of soil to be remediated.

Step 2. Select a tentative treatment location.

Step 3. Identify and contact applicable regulatory agencies. The local environmental agency is usually used for air permits, while the state environmental agency is usually used for identifying cleanup levels.

Step 4. Negotiate the target cleanup levels and final soil disposition. Obtain a written memo from the regulatory agency confirming the agreed-upon cleanup levels, and all documentation and permits that will be required for the project.

Step 5. Negotiate the number, locations, and intervals of soil sampling.

Step 6. Negotiate with regulators not to require off-gas treatment in cases where the primary contaminant is a heavy hydrocarbon supporting minimal VOC emissions.

Step 7. Work through the lead agency to obtain the proper permits.

SECTION 3
BIOCELL DESIGN

3.1 BIOCELL DESIGN

The baseline biocell design presented herein has been sized to accommodate 40 yd^3 of contaminated soil. It is based on the Army's Waterways Experiment Station's design using a roll-off dumpster. However, the blower should pull the air through the soil and GAC canisters versus blowing the air, as demonstrated by WES, to eliminate the potential for VOCs to escape through the cover. If the permit does not require off-gas treatment, blowing air through the soil is recommend.

A 40 yd^3 container comes in various physical dimensions, however, this document deals with an 8 ft wide by 22 ft long by 7 ft high container. Once the biocell site has been selected (Section 2.3), and the proper permits (Section 2.1) have been obtained, biocell construction can begin. The number of biocells and the size of the soil staging area are based on the volume of soil to be treated annually. Figure 3-1 shows a schematic of a single biocell.

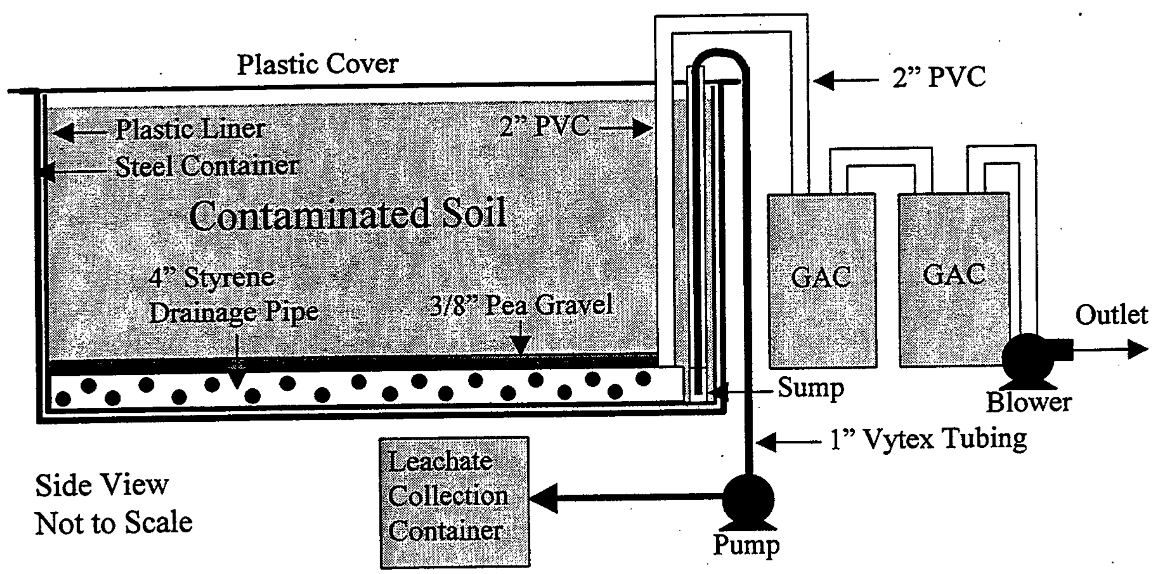

Figure 3-1 Schematic of a biocell.

A pump shed may be used to house the pump, blower, and tools. Although the shed is not required, it offers convenient protection and storage for equipment. These sheds are commonly sold at large hardware stores and come in many sizes. A typical size shed used for a biocell is 8 ft by 10 ft.

Although specially designed leak-free containers can be built to specifications, the commercially available roll-off dumpster is usually the most cost effective. A lists of a few vendors supplying roll-off dumpsters, pumps, blowers and GAC is available from the Naval Facilities Engineering Service Center. Screened PVC, styrene drainage pipe, and pea gravel may be purchased from any local well drilling supply store. The styrene drainage pipe and a plastic tarp may also be purchased from a local building supply store. Pea gravel may also be purchased from any local gravel supply store.

A list of parts needed for building one 40 yd^3 biocell is given in Table 3-1. The quantity of the parts listed is a rough estimate. The construction of the biocell also requires a front-end loader or bucket loader, an operator, a minimum of two laborers, health and safety equipment, and possible soil processing equipment.

Table 3-1 Example Parts List for a 40 yd^3 Biocell

Framework:	**Leachate Collection System:**	**Aeration System:**	**GAC Off-Gas Collection:**
40 yd^3 Dumpster	1 - ½-hp Self-Priming Centrifugal Pump	4 - 10' Length Styrene Drainage Pipe	30'- 2" PVC Pipe
22 x8' Tarp to Fit Top of Dumpster	1 - 8' Length 0.010-2" Screened PVC Pipe	2 - 4" to 2" PVC Reducing Couplings	2 - 2' Length 0.010-2" Screened PVC Pipe
38 x24' 20-mil Liner	50' - 1" Vytex Tubing	1 - 1-Hp Blower	8 - 2" PVC Elbows
Rope	1 - 10' Length 2" PVC Pipe	40' - 2" PVC Pipe	4 - 2" Unions
	1 - 2" PVC Elbows	1 - 2" PVC Tee	4 - 2" PVC Couplings
	1 - Hose and Brass Nozzle	2 - 4" PVC Caps	2 - GAC Drums
	1 - 1" Check Valve	2 - 4" PVC Unions	
	2 - Pump Fitting to 1" Tubing	1 - 2" PVC Ball Valve	
	1 - 55-Gallon Drum	4 - 2" PVC Elbows	
	8 ft^3 - Filter Pack Bags	2 - 4" PVC Elbows	
		44 ft^3 - 3/8" Pea Gravel Bag	

3.2 LEACHATE COLLECTION SYSTEM

The primary purpose for the leachate collection system is to keep the soil from becoming saturated at the bottom of the biocell. During normal operations there should be little or no leachate produced. However, if leachate is produced it should be collected in a container. The container may be a 55-gallon drum. Periodic soil samples will indicate the moisture content. If the soil moisture content becomes less than 10 percent, the leachate should be reintroduced to the biocell as moisture. The leachate pump may be used to spray the leachate on the soil surface.

The leachate collection system consists of screened PVC pipe, a 1/2-hp self-priming centrifugal pump and a collection container. The pump is used to transfer leachate out of the biocell into the collection container and to pump leachate from the container back into the soil when necessary. A 20-mil plastic liner should be placed in the dumpster prior to the installation of the leachate collection system. The liner should be flexible enough to bend in the corners when lining the biocell. The liner should extend all the way up the sides to the top lip of the container. The system consists of 2" screened 0.01" PVC (well pipe) allowing leachate to flow to a sump which extends vertically out the top of the biocell. The leachate pipe should be covered with a filter pack to keep silts from entering the pipe. The biocell should be a graded surface with a minimum of ¼" per foot, or about 1 degree, toward the end of the biocell where the leachate collection pipe and sump are located (see Figure 3-2). A Vytex tube, or flexible plastic tubing, should be inserted down the sump to the bottom through which any leachate may be pumped out into the collection container. The tube should have a check valve to prevent backflow or loss of prime.

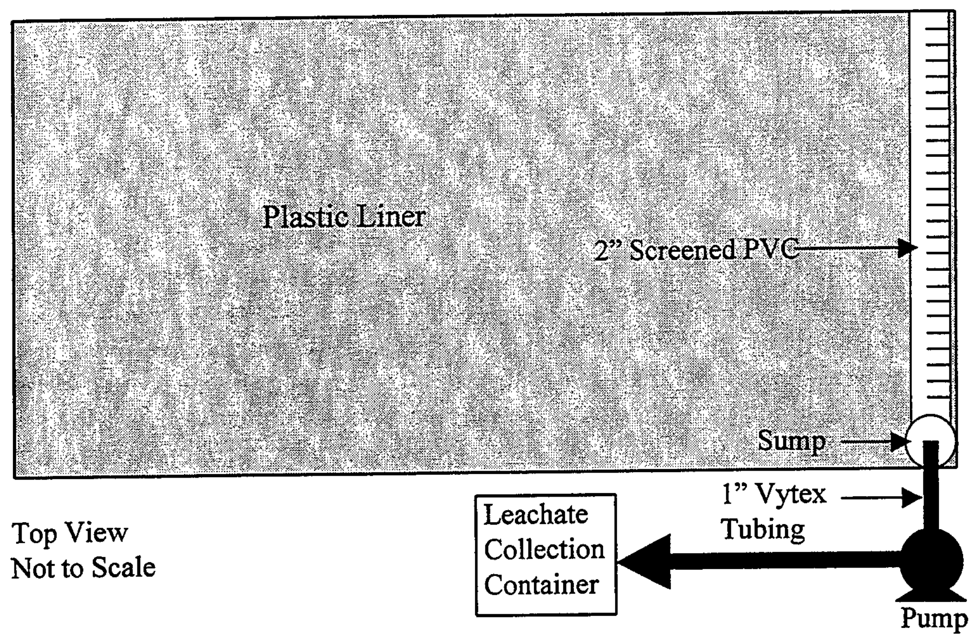

Figure 3-2. Schematic of the leachate collection system.

3.3 AERATION SYSTEM

The biocell must be adequately aerated to promote efficient degradation of contaminants by microorganisms. Of all the metabolic factors, oxygen is the most important, so efficient aeration is essential to biocell operation. Air is injected with a blower into the biocell through perforated pipes located above the leachate collection system. Typically, airflow rates through the soil are sufficient enough to keep the soil above oxygen-limiting conditions. Such flow rates prevent excess volatilization of hydrocarbons, thus reducing the vapor emissions. The contaminant volatilization rate is dependent on the type of contaminant present in the biocell.

Off-gasses are passed through a treatment system to destroy contaminant vapors. Granular activated carbon (GAC) is used for the treatment of discharge vapors. When the TPH contamination is a heavier fuel (diesel or heavier), off-gas treatment may not be necessary. Efforts should be made to negotiate with regulators not to require biocell off-gas treatment in cases where the primary contaminant is a heavier hydrocarbon. In some cases, initial vapor treatment followed by no vapor treatment may be an appropriate option. Vapor treatment could be stopped once TPH concentrations in the biocell exhaust have decreased below a negotiated level. If during the initial feasibility analysis and permitting process exhaust gas treatment becomes necessary, two activated carbon canisters can be installed in series to remove VOCs. Duplicate carbon canisters can be installed to ensure continued off-gas treatment should the first canister reach the contaminant breakthrough stage.

The design of the aeration system is based on pulling air through the soil. The basic aeration system components include a blower, a manifold header pipe connected to the blower, and a valve at the blower (see Figure 3-3). Two aeration pipes should be placed directly on the bottom liner and covered 3 to 4" with 3/8" pea gravel (see Figure 3-4). Each aeration leg should be plumed vertically out the top and down the outside of the biocell (see Figure 3-1). The legs should be joined to the manifold header, to a valve, and then to the blower. The valves are used to adjust the airflow and should have a lock down to prevent the valves from accidentally turning during operation. The legs should be made the same length and the blower should be positioned in the middle of the manifold header to allow equal flow through the legs. Each leg should be constructed from 4" styrene drainage pipe (screened PVC pipe may be used but is more expensive); with one end capped and the other end having an elbow which reduces to a 2"pipe (manifold header) connected to the blower. An automatic on/off timer switch is recommended to run the blower. For a single biocell, the blower should run approximately 15 to 20 minutes every day. The blower may need to run longer for multiple biocells to ensure the same volume of air passes through the soil. If multiple biocells are used, the flow to each biocell must be equalized by measuring the flow to each biocell and adjusting with valves. Flow may be measured using a hot wire anemometer. Housing the blower in a shed will protect it from the weather. The same shed can serve as a storage area for miscellaneous equipment and tools.

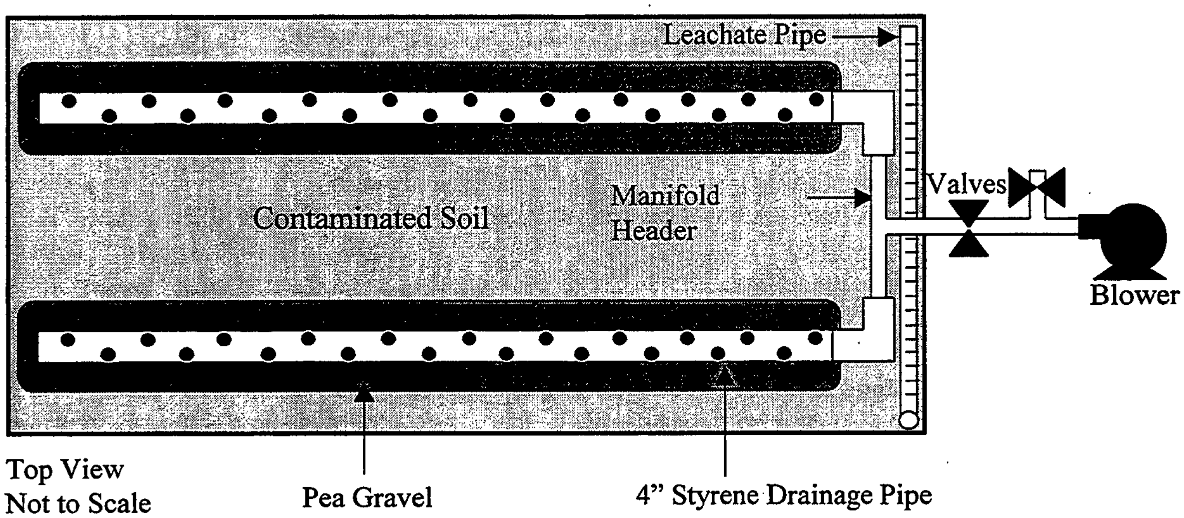

Figure 3-3. Schematic of the aeration system.

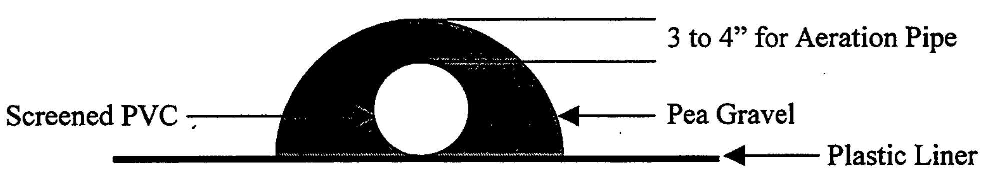

Figure 3-4. Placement of pea gravel.

3.4 SOIL pH

The soil pH may influence the bioremediation process because soil microorganisms require a specific pH range to survive. Most bacteria function in a pH range between 5 and 9, with the optimum being slightly above 7 (Ref. 4). A shift in pH may result in a shift in the microbial population because different species will exhibit optimal growth at a specific pH. Very few soils will require radical adjustment of the pH prior to forming the biocell. If soil sampling and analysis indicates that the pH is out of the optimal range, amendments can be introduced during the initial soil preparation. If the soil pH is too acidic, lime may be added to increase the pH. If the soil pH is too basic, sulfur, ammonium sulfate, or aluminum sulfate may be added to decrease the pH (Ref. 5).

3.5 TEMPERATURE

Temperature has an affect on both the physical state and the biodegradation rates as associated with petroleum hydrocarbons. Unless the soil completely freezes, biodegradation will occur in colder climates but at a slower rate. Soil that is treated in-situ generally remains cool, but due to insulating properties found in high volumes of soil the temperature remains quite stable. However, variability of temperature in soil due to daily or seasonal fluctuations is particularly noticeable when ex-situ or aboveground treatments are used. Microbial degradation rates are expected to double with every 10^0 C increase in temperature (Ref. 6).

3.6 MOISTURE AND NUTRIENT ADDITION

Microorganisms require moisture to transport nutrients, to carry out metabolic processes, and to maintain cell structure. However, excessive moisture is undesirable because: (a) when water occupies a high fraction of the pore space in the soil, the air permeability declines, reducing available oxygen, and (b) excess moisture will increase leaching of contaminants and nutrients from the soil. Generally, when aerobically bioremediating soils, moisture content is considered optimal between 10 to 20 percent by weight (Ref. 3).

The contaminants and natural organic compounds in the soil typically provide an adequate amount of carbon, but the availability of other essential nutrients such as nitrogen and phosphorus may be insufficient compared to the quantity of carbon. Typically, the carbon to nitrogen to phosphorus (C:N:P) ratio is 100:15:1 (Ref. 1). The moisture and nutrient contents of the soil to be treated in the biocell can be readily adjusted during the initial preparation of the soil. At some sites, little or no initial water addition will be needed. The moisture content of the soil may change as the remediation proceeds. Depending on the site conditions, it may be necessary to add moisture during biocell operation. When the biocell begins to dry out, leachate and/or water is sprayed to the top of the soil.

The nutrient solution can be mixed with water in the 55-gallon leachate tank and sprayed onto the soil using the leachate pump and a garden hose. There should be marks inside the drum indicating volume increments to tell the user how much water or nutrients will be applied to each loaded bucket. As the soil is slowly dropped into the biocell, the nutrient solution should be applied with a fine mist spray. The flow rate can be calculated by timing how long it takes to fill a 5-gallon bucket with the nutrient solution. The soil application rate is merely the number of buckets the loader applies to the biocell per unit time. Table 3-2 indicates the composition, percent nitrogen and phosphorus, and weight fractions of several agricultural chemicals that can be used to adjust the nutrient content of soil. The amount of nutrient addition may be calculated using Table 3-3. Table 3-4 shows an example nutrient addition worksheet to guide the operator through the calculations.

Table 3-2. Types of Nutrient Sources

Name	Formula	Percent N:P	Weight Fractions	Vendor Quoted
Urea	$CO(NH_2)_2$	46:0	N = 0.46	Lesco
Superphosphate	$Ca(H_2PO4)_2$	0:27	P = 0.27	Lockbourne Farmers Exchange

Table 3-3. Biocell Nutrient Addition Worksheet

BIOCELL NUTRIENT ADDITION WORKSHEET

1. Nutrient Source (see Table 3-2 for weight fractions):
   a. Nitrogen source________________weight fraction nitrogen________________
   b. Phosphorus source________________weight fraction phosphorus________________

2. Carbon Source:
   a. Concentration of hydrocarbon contamination (TPH) in soil = ____________mg/kg dry soil
   Obtain from laboratory results.
   b. Carbon content in contamination = line 2a x 0.8 = ____________mg carbon/kg dry soil

3. Desired C:N:P ratio. Suggest C:N:P = 100:15:1

4. Amount of nutrient to add per kg of dry soil:
   a. Nitrogen (N) needed to be added per kg dry soil = line 2b x 0.15 =____________mg/kg soil
   b. Phosphorus (P) needed to be added per kg dry soil = line 2b x 0.01 =____________mg/kg soil

5. Bulk density of soil =____________kg/m^3. (Assume 1,400 kg/m^3 if unknown.)

6. Kilograms of nutrients required per m^3 of soil:
   a. Nitrogen (N) kg/m^3soil = line 4a x line 5 ÷ 1,000,000 =____________kg/m^3 soil
   b. Phosphorus (P) kg/m^3 soil = line 4b x line 5 ÷ 1,000,000 = ____________kg/m^3 soil

7. Pounds of nutrients required per yd^3 of soil:
   a. Nitrogen (N) lb/yd^3 soil = line 6a x 1.69 =____________lb/yd^3 soil
   b. Phosphorus (P) lb/yd^3 soil = line 6b x 1.69 =____________lb/yd^3 soil

8. Total volume of soil to be treated by biocell:__________yd^3

9. Pounds of nutrients to be added per cubic yard of soil:
   a. line 7a ÷ line 1a = ____________lb of N source required/yd^3 soil
   b. line 7b ÷ line 1b = ____________lb of P source required/yd^3 soil

10. Total pounds of nutrient sources required for the biocell:
    a. line 9a x line 8 = ____________lb of N source to be purchased
    b. line 9b x line 8 = ____________lb of P source to be purchased

Table 3-4. Example Nutrient Addition Worksheet

EXAMPLE NUTRIENT ADDITION WORKSHEET

1. Nutrient Source (see Table 3-2 for weight fractions):
   a. Nitrogen source ___*Urea*___ weight fraction nitrogen ___*0.46*___
   b. Phosphorus source ___*Superphosphate*___ weight fraction phosphorus ___*0.27*___

2. Carbon Source:
   a. Concentration of hydrocarbon contamination (TPH) in soil = ___*Assume 2,000*___ mg/kg dry soil
      Obtain from laboratory results.
   b. Carbon content in contamination = line 2a x 0.8 = ___*1,600*___ mg carbon/kg dry soil

3. Desired C:N:P ratio. Suggest C:N:P = 100:15:1

4. Amount of nutrient to add per kg of dry soil:
   a. Nitrogen (N) needed to be added per kg dry soil = line 2b x 0.15 = ___*240*___ mg/kg soil
   b. Phosphorus (P) needed to be added per kg dry soil = line 2b x 0.01 = ___*16*___ mg/kg soil

5. Bulk density of soil = ___*1,400*___ kg/m^3. (Assume 1,400 kg/m^3 if unknown.)

6. Kilograms of nutrients required per m^3 of soil:
   a. Nitrogen (N) kg/m^3soil = line 4a x line 5 ÷ 1,000,000 = ___*0.336*___ kg/m^3 soil
   b. Phosphorus (P) kg/m^3 soil = line 4b x line 5 ÷ 1,000,000 = ___*0.022*___ kg/m^3 soil

7. Pounds of nutrients required per yd^3 of soil:
   a. Nitrogen (N) lb/yd^3 soil = line 6a x 1.69 = ___*0.568*___ lb/yd^3 soil
   b. Phosphorus (P) lb/yd^3 soil = line 6b x 1.69 = ___*0.038*___ lb/yd^3 soil

8. Total volume of soil to be treated by biocell: ___*40*___ yd^3

9. Pounds of nutrients to be added per cubic yard of soil:
   a. line 7a ÷ line 1a = ___*0.261*___ lb of N source required/yd^3 soil
   b. line 7b ÷ line 1b = ___*0.010*___ lb of P source required/yd^3 soil

10. Total pounds of nutrient sources required for the biocell:
    a. line 9a x line 8 = ___*10.44*___ lb of N source to be purchased
    b. line 9b x line 8 = ___*0.40*___ lb of P source to be purchased

3.7 SOIL PROCESSING AND LOADING

In soils with high clay content, soil shredding may be needed to improve the soil structure and porosity allowing proper airflow. Some highly contaminated soils pack tightly together to form large, sticky clumps. Air cannot effectively penetrate such clods. As a result, the microbial degradation rate and final achievable reduction in contamination will decline. Some hand removal of large rocks, dirt clots, or debris may be required.

Generally, soils with TPH contamination in excess of 50,000 mg/kg will require blending with uncontaminated or less-contaminated soil. However, such levels are not common in UST sites. During excavation, the peak contaminant levels are reduced because highly contaminated soil becomes mixed with surrounding soil that is less contaminated. For cases where the soils are blended, water and nutrients can be introduced into the mixer along with the soil. Prior to any soil blending or shredding, a screening step should occur to remove rocks and debris. Crushing and mixing of the soil may be desirable to increase the contaminant homogeneity and improve the soil permeability, and will likely eliminate the need to add a bulking agent (Ref. 7).

Soils should be prescreened for moisture content and contaminant levels to estimate treatment times and moisture/nutrient additions. Soil may be loaded into the biocell using a front-end or bucket loader. As the soil slowly falls into the reactor, the first amount of the moisture/nutrient mixture should be sprayed in a fine mist on the soil, making sure to use the correct amount for that 1 ft. layer of soil. This should continue until the soil is approximately 6" below the top of the container. See Section 3.4 for recommendations on adding moisture and nutrients to the soil during loading.

After the biocell operation is completed, a backhoe may be used to remove some of soil from around the door. Extreme care should be taken when opening the door since the weight of soil may dangerously force the door open. When the door is opened, a backhoe or BOB-CAT can easily remove the remaining soil.

3.8 COVER INSTALLATION

After the soil has been loaded, the cover may be installed. The cover should be a waterproof plastic liner or tarp and should cover the top of the 22 by 8 ft biocell. A tarp may be purchased from any local building supply store. The tarp should have eyelets to allow rope to secure the cover.

SECTION 4
BIOCELL OPERATION AND MAINTENANCE

Biocell treatment requires a period of operation and maintenance (O&M) before cleanup goals can be reached. Typically, a biocell is operated for 3 to 6 months, at which time the treated soil should meet the remedial objectives. Well thought-out plans for O&M and closeout are required to ensure high-quality, safe, and cost-effective treatment.

4.1 BIOCELL SYSTEM STARTUP

An initial inspection should be conducted to ensure all biocell system components are installed and operating properly. A visual inspection of the biocell cover, blower, blower piping, instrumentation, and off-gas treatment system should be performed. It is particularly important to ensure that the inlet and discharge lines of the blower are not obstructed. Operation of the blower with low airflow due to obstructed discharge will result in overheating and eventual damage to the blower.

4.2 SOIL SAMPLING

Soil should be periodically sampled for contamination and for moisture content. Review the permit for the, number, locations, and interval of soil sampling. A variety of methods are available to collect soil samples; however, the hand-auger sampling method is the best suited for sampling in a biocell. Use the hand auger to bore a hole to approximately 1 ft above the desired sampling depth. Next, use a slide hammer-type hand sampler lined with brass sleeves (two 6" sections) to collect a core sample. Remove, cap, and label the two brass sleeves containing the soil sample. Upon labeling the samples, complete a chain-of-custody form and place the sample in a cooler chilled with artificial ice. Upon completion of sampling, transport the samples to a test lab. Samples should be tested for TPH concentrations by following EPA method 8015M.

4.3 ROUTINE OPERATIONS

Once installed, the biocell should be operated in a flexible manner to optimize biological destruction of contaminants while limiting the quantity of contaminants removed by vapor transport. Periodic monitoring is required to measure system performance, and system adjustments may be needed to adapt to declining contaminant concentrations or other changing conditions in the biocell.

A walk-by check to confirm normal operation of the system should be performed weekly. The walk-by should include visual inspection of the cover, blower, and piping. The operator should also be alert for unusual sounds or odors. A loud rattling noise from the blower may indicate bearing failure, or other undesirable conditions. Odors may indicate that the pile is not adequately aerated or that the off-gas system is not operating effectively (plugged). Monthly checks and measurements of the off-gas treatment system and leachate handling system may be adequate, but more frequent inspections may be required for regulatory compliance.

4.4 LABOR REQUIREMENTS

The biocell system is designed to be simple, cost effective, and should require very little time for construction and O&M. It is estimated that one worker and one backhoe operator will take 1 day to construct a biocell. The biocell will also require approximately 2 hours for weekly inspections and 4 hours for monthly soil and gas sampling, but more frequent inspections and sampling may be required for regulatory compliance.

4.5 TREATMENT DURATION

The treatment time needed to treat the soil depends on the local climatic conditions, the soil type, the level of contamination, and the cleanup goals specified in the permit. Table 4-1 shows the duration of treating soil in different geographical locations, based on the soil having the same concentration and soil type. Biocells operating in temperate climates, such as California, will take 3 to 6 months to attain cleanup goals. Biocells operating in warmer climates, such as Hawaii, will treat soil faster than colder climates such as Alaska.

Table 4-1. Duration of Treating Soil in Different Geographical Locations

Geographical Locations	Annual Avg. Temperature	Treatment Duration
Anchorage, Alaska	36^0 F	4 to 8 months
Los Angles, California	66^0 F	3 to 6 months
Honolulu, Hawaii	77^0 F	3 to 5 months
Keflavik, Iceland	41^0 F	4 to 8 months
Norfolk, Virginia	59^0 F	3 to 6 months

The laboratory results of the last soil samples taken will demonstrate when the required cleanup goals have been achieved. Cleanup goals will be specified for different contaminants by the regulatory requirements in the permit. Petroleum hydrocarbons are the most common contaminants treated in biocells, so the most common cleanup goal specification is based on TPH. Benzene, toluene, ethylbenzene, and xylenes (BTEX) are components of petroleum hydrocarbon materials that frequently are targeted by regulators in specifying cleanup goals. When BTEX compounds are present, the cleanup goals required for these compounds will be more stringent than for TPH. Attainment of cleanup goals for the soil should be documented in a soil treatment report. Before preparing the report, the biocell operator should determine the format and content required by the lead regulatory agency. A typical report will cover the types of contaminants, initial concentrations, cleanup goals, biocell design and operating features, results of sampling and analysis that verify attainment of cleanup goals, and the final soil disposition (Ref. 8).

SECTION 5
ECONOMICS

This section analyzes the economics of the biocell systems. As discussed earlier in Section 1.3, a single container at a time is capable of treating contaminated soils ranging in quantities from 20 to 40 yd^3. For treating soil quantities exceeding 40 yd^3, multiple containers operated simultaneously will be required. Based upon practical and economical considerations, up to three containers could be deployed at a site. The unit cost of soil treatment in dollars per yd^3 depends upon the capital costs, annual operating and maintenance costs, treatment time for each batch of soil, and system useful life. This analysis further assumes that labor to construct, operate, and maintain the biocell is supplied by the activity at no cost to the project.

5.1 SYSTEM CAPITAL COSTS

The capital cost of the basic components of a biocell for one, two, and three-biocell configurations is given in Table 5-1. It should be noted from the tabulation that the multiple container configurations could share the blower, pump, and GAC canisters to minimize capital costs. The system capital costs are $5,000 for a single biocell, $8,100 for a two-biocell system, and $11,200 for a three-biocell system.

5.2 ANNUAL OPERATION AND MAINTENANCE COSTS

The annual O&M costs depend upon the number of operations of the biocell per year and the quantity of soil treated annually. A break down of these costs is given in Table 5-2 which shows the annual costs of various consumable materials associated with a single, two, and three-container system. These costs do not include any labor costs needed to operate and maintain the systems. As shown, the annual O&M costs are $3,900 for a single biocell, $7,200 for a two-biocell system, and $10,200 for a three-biocell system.

5.3 TREATMENT DURATION

Although the treatment duration, described in Section 4.5, can range from 3 to 6 months, this cost analysis is for operating a biocell in Southern California with temperate weather conditions year round. Therefore, the biocell can treat three batches of soil per year with each batch requiring 4 months.

5.4 SYSTEM LIFE

Although most mechanical equipment can last for 15 years, the biocell components may not. This is due to exposure to contaminated soils, toxic fumes, and the ambient weather, which could cause excessive wear and tear and thus reduce the system useful life. Therefore, for this analysis, the system useful life is assumed to be 5 years.

5.5 UNIT COST OF TREATMENT

The unit cost, in dollars, for treating contaminated soils using biocell systems can be computed as follows:

Total annualized cost = (System capital cost/System useful life in years) + Annual O&M costs

Unit treatment cost/yd^3 = Total annualized costs/quantity of soil treated annually

The unit cost of treatment was computed by using the information given in Tables 5-1 and 5-2 and the results are shown in Table 5-3. The results are plotted in Figure 5-1 for comparison. The results show that the unit costs per yd^3, amortized over 5 years with three operations per year, are \$40.83/yd^3 for one biocell, \$36.75/yd^3 for two biocells, and \$34.56/yd^3 for three biocells, respectively. As the number of operations per year increase, the unit cost per yd^3 decreases. For example, one biocell has a unit cost of \$57.50/yd^3 at one operation per year, but at three operations per year, the cost decreases to \$40.83/yd^3. In addition, to treat 80 yd^3 per year it is cheaper to use one biocell twice a year than to use two biocells once a year. For example, to treat 80 yd^3 per year with one biocell at two operations per year the unit cost is \$45.00/yd^3, but with two biocells at one operation per year, the unit cost increases to \$50.25/yd^3. When the container is not at full capacity the costs per yd^3 are significantly higher. Therefore, soil should be stockpiled until the biocell may be operated at 100 percent capacity. Based on a survey conducted by the Naval Facilities Engineering Service Center the Navy has at least 11 facilities spending between \$40 to \$480/yd^3 for off-site disposal (Ref. 9).

Table 5-1. Capital Costs

Basic Components	**Costs for 1 Biocell**	**Costs for 2 Biocells**	**Costs for 3 Biocells**	**Comments**
Roll-off dumpster purchased	\$3,000	\$6,000	\$9,000	
1-hp blower	\$600	\$600	\$600	Can be used for multiple biocells
½-hp pump	\$300	\$300	\$300	Can be used for multiple biocells
2 GAC canisters	\$1,000	\$1,000	\$1,000	Can be used for multiple biocells
Plumbing	\$100	\$200	\$300	Half of plumbing can be reused
Total	**\$5,000**	**\$8,100**	**\$11,200**	

Table 5-2. Annual Operation and Maintenance Costs

Consumable Components	**O&M Costs/Year**			**Comments**
	For 1 Biocell	**For 2 Biocells**	**For 3 Biocells**	
Cover	\$50	\$100	\$150	Can be used reused
Plastic liner	\$250	\$500	\$750	Will tear during unloading
Plumbing	\$100	\$200	\$300	Half of plumbing can be reused
Other materials (nutrients, filter pack, pea-gravel, etc.)	\$100	\$200	\$300	
Sampling (Soil/Gas lab analysis)	\$800	\$1400	\$1900	
Electricity	Negligible	Negligible	Negligible	Will cost less than \$2/operation
Total Costs, 1 operation/year	\$1300	\$2400	\$3400	
Total Costs, 2 operations/year	\$2600	\$4800	\$6800	
Total Annual Costs, 3 operations/year	**\$3,900**	**\$7,200**	**\$10,200**	

Table 5-3. Unit Treatment Cost/yd³

No. Biocells	Operations/Year	yd³/Year	Total Annualized Cost	Unit Treatment Cost/yd³
1	1	40	2,300	57.50
	2	80	3,600	45.00
	3	120	4,900	40.83
2	1	80	4,020	50.25
	2	160	6,420	40.13
	3	240	8,820	36.75
3	1	120	5,640	47.00
	2	240	9,040	37.67
	3	360	12,440	34.56

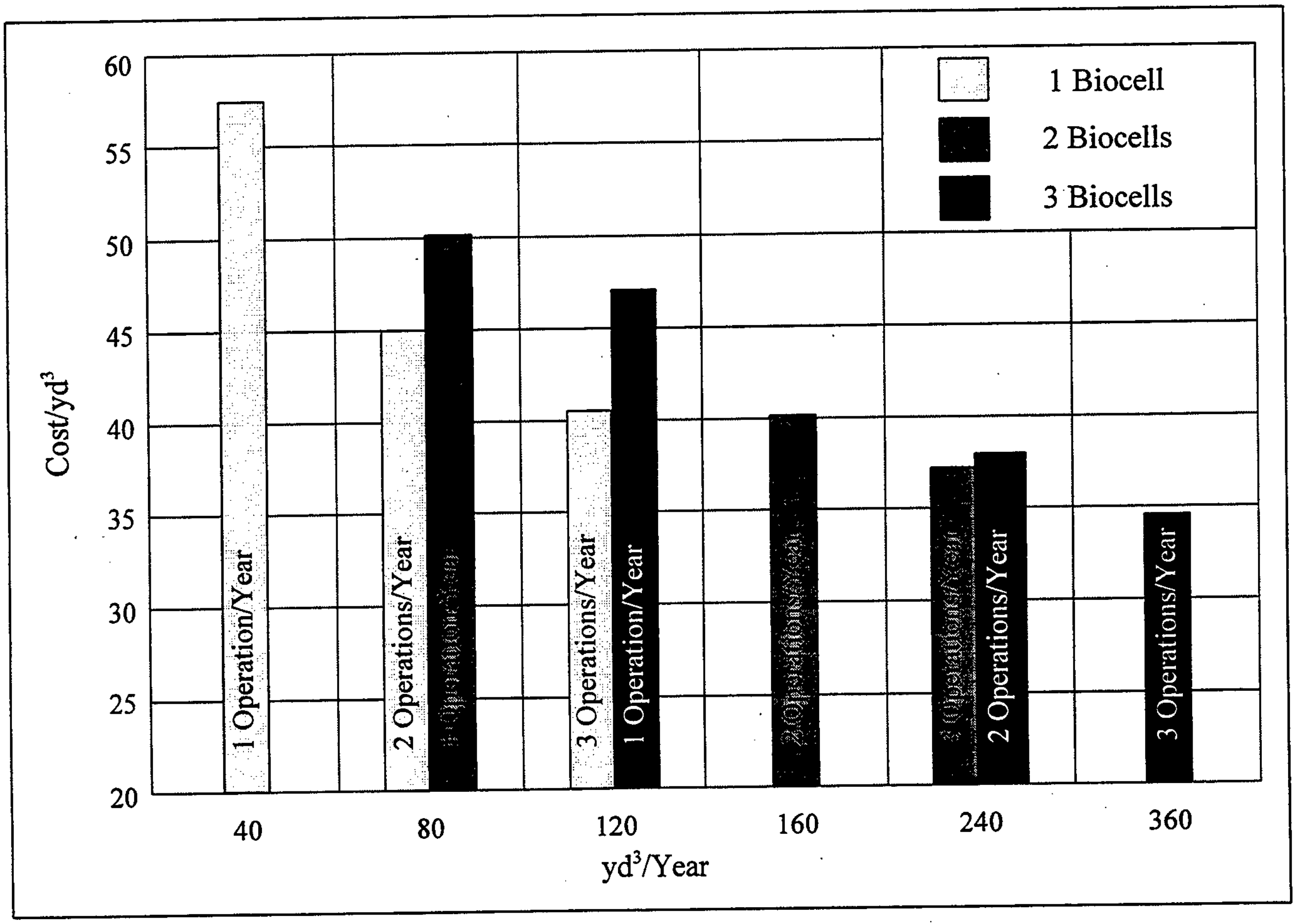

Figure 5-1. Unit cost per yd³ at multiple operations per year.

SECTION 6
SUMMARY

This guidance was developed to provide Navy installations a general overview of the biocell technology, design, operation and maintenance procedures, and economics. Biocell technology may easily be implemented to treat soils with concentrations of petroleum hydrocarbons, which are commonly encountered at Navy installations. The technology involves loading petroleum-contaminated soils into a dumpster or container, and stimulating aerobic microbial activity within the soils through aeration. Soil can be treated in a 40 yd^3 container in amounts ranging from a small quantity, by simply filling a portion of the container, to a large quantity, by using multiple containers (modular approach). The unit costs per yd^3, amortized over 5 years with three operations per year, are \$40.83/yd^3 for one biocell, \$36.75/yd^3 for two biocells, and \$34.56/yd^3 for three biocells, respectively. When the container is not at full capacity the costs per yd^3 are significantly higher. Therefore, soil should be stockpiled until the biocell may be operated at 100 percent capacity. When compared to off-site disposal costs, which range from \$40.00/yd^3 to \$480.00/yd^3, biocell technology could be a very cost effective option.

SECTION 7
REFERENCES

1. Naval Facilities Engineering Service Center. TM-2189-ENV: Biopile design and construction manual. Port Hueneme, CA, 1996.

2. U.S. Waterways Experiment Station. Miscellaneous Paper EL-97-xx: Biocell pilot testing of TPH contaminated soil, by M.R. Burchell II, M.E. Zappi, R.T. Morgan, and J. Talley. Vicksburg, MS, 1997.

3. R.B. King, G.M. Long, and J.K. Sheldon. Practical environmental bioremediation. Ann Arbor, MI, Lewis Publishers, 1992.

4. J. Dragun. "Microbial degradation of petroleum products in soil," in E.J. Calabrese and P.T. Kostecki (Eds.), Soils Contaminated by Petroleum Products: Environmental and Public Health Effects. New York, NY, John Wiley & Sons, Inc., 1988, pp 289-300.

5. M.H. Huesemann. "Guidelines for land-treating petroleum hydrocarbon-contaminated soils," Journal of Soil Contamination, vol 3, no. 3, 1994, pp 299-318.

6. U.S. Army Engineer Waterways Experiment Station. Technical Report EL-91-13: Evaluation of the potential for use of microorganisms in the cleanup of petroleum hydrocarbon spills in soils, by D. Gunnison. Vicksburg, MS, 1991.

7. D.R. Eiermann and R. Bolliger. "Bioremediation of a PAH-contaminated gasworks site with the Ebiox vacuum heap system," in R.E. Hinchee, J.A. Kittel, and H.J. Reisinger (Eds.), Applied Bioremediation of Petroleum Hydrocarbons. Columbus, OH, Battelle Press, 1995, pp 241-248.

8. Naval Facilities Engineering Service Center. TM-2190-ENV: Biopile operations and maintenance manual. Port Hueneme, CA, 1996.

9. Naval Facilities Engineering Service Center. Survey of Naval Facilities Potentially Requiring a Biocell., by D. Pal. Port Hueneme, CA, May, 1997.